An Experimental Exploration of Voluntary Mechanisms to Reduce Nonpoint Source Water Pollution with a Background Threat of Regulation

Jordan F. Suter[1], Christian A. Vossler[2], Gregory L. Poe[1], William D. Schulze[1] and Kathleen Segerson[3]

[1]Department of Applied Economics and Management, Cornell University, Ithaca, NY 14853
[2] Department of Economics, University of Tennessee, Knoxville, TN 37996
[3] Department of Economics, University of Connecticut, Storrs, CT 06269

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Please direct correspondence to Suter (jfs24@cornell.edu). Research supported by US EPA Grant R830989 and USDA Hatch Funds (121-7829).

Improvements in surface water quality since the passage of the Federal Clean Water Act Amendments of 1972 have come primarily as a result of reductions in emissions from point sources, such as wastewater treatment plants and factories. While opportunities for further emissions reductions from point sources do remain, it is nonpoint source pollution that presently represents the greatest share of surface water impairment in the United States (Ribaudo 2003). Agricultural production, which occurs on approximately 60% of nonfederal land in the US (NRI 2002), is the largest component of nonpoint source water pollution and represents the leading source of water quality impairments among the rivers and lakes surveyed in the 2000 *National Water Quality Inventory* (US EPA 2002).

Given the role of nonpoint sources in influencing water quality, economic theorists have devised a number of regulatory approaches designed to reduce surface water pollution stemming from agricultural production. These approaches can be roughly broken into performance-based policies, which base regulation on measurable outcomes, and design-based policies, which are predicated on input decisions (Ribaudo 1999). Since nonpoint source emissions are characterized as prohibitively costly to monitor on a firm-by-firm basis, performance-based policies have been directed towards ambient environmental conditions. Beginning with the seminal work of Segerson (1988), numerous regulatory approaches that provide incentives to nonpoint source polluters based on ambient pollution levels have been proposed (e.g., Xepapadeas 1991; Cabe and Herriges 1992; Hansen 1998; Horan et al. 1998; Karp 2004).

In recent years a burgeoning set of studies have complemented the theoretical literature by testing many of the proposed regulatory policies in an experimental economics laboratory setting (Spraggon 2002, 2004; Alpizar et al. 2004; Poe et al. 2004, Cochard et al. 2005, Suter et al. 2005, Vossler et al. 2006). The results from these experimental studies show that a subset of the proposed theoretical policies engender outcomes that are highly efficient. In particular, a policy that administers a per unit tax on ambient pollution above a pre-specified threshold has been shown to bring about socially desirable levels of emissions. This result is robust to the specific tax threshold that is chosen and the nature of communication that occurs.

In this paper we build on a voluntary mechanism introduced by Segerson and Wu (2006) that uses the threat of an ambient tax to induce nonpoint source polluters to reduce emissions. After reviewing Segerson and Wu's policy, we propose a new voluntary/threat policy that offers some theoretical advantages over that put forward by Segerson and Wu. We then test various forms of voluntary/threat policies in the experimental economics laboratory and compare the outcomes to a policy that administers strictly a per unit ambient tax.

A voluntary mechanism that uses regulation as a background threat is of policy interest because policy makers have historically addressed nonpoint source pollution almost exclusively through voluntary measures[1]. While voluntary programs have been widely accepted by agricultural producers, there is little evidence that they have delivered outcomes, in terms of improved water quality, that would warrant declaring them a success (Shortle, Abler and Ribaudo 2001). A recent study by the US Environmental Protection Agency (EPA) finds that almost 35 years after the passage of the Clean Water

[1] Common voluntary policies include land retirement programs, such as the Conservation Reserve Program, as well as working land programs, that provide incentives to agricultural landowners for developing best management practices (BMPs) and implementing pollution prevention and control measures. Annual federal expenditures for voluntary conservation programs are projected to be nearly $5 billion by 2011 (ERS 2002)

Act, nearly 70% of all stream miles in the United States can be classified as being in "fair" or "poor" condition (US EPA 2006).

In an effort to wed the political palatability of a voluntary policy and the theoretical attractiveness of an appropriately designed regulatory policy, Segerson and Wu (2006) introduce a policy that uses voluntary and regulatory programs as complementary instruments. The essence of the proposed policy allows firms in a watershed to voluntarily meet a given ambient pollution target. As long as the ambient target is achieved, no regulatory fees are charged. If, however, the target is not met voluntarily, then a regulatory instrument is put in place, whereby all firms are subject to an ambient-based pollution tax. The regulatory portion of the policy, by imposing a threat of high expected costs, theoretically induces firms to meet the ambient pollution target voluntarily.

The proposed voluntary policy with threat of regulation has some clear advantages over a strictly regulatory or strictly voluntary approach. From a producer's standpoint this policy is attractive because it allows for flexibility in meeting pollution standards without explicit regulation. From the regulator's standpoint the policy's attractiveness comes from avoiding the potential large costs involved with administering the tax and incurring the information costs necessary to appropriately set the tax rate. Finally, the instrument is attractive from the social planner's perspective, as it offers the potential to cost effectively address the nonpoint source pollution problem.

A shortcoming of the Segerson and Wu framework is the coordination problem in the voluntary setting resulting from the possible existence of multiple Nash Equilibria, including zero abatement (Segerson and Wu 2006). To reduce the multiplicity of Nash

Equilibria, we replace Segerson and Wu's exogenously determined tax threshold with one that is determined based on the level of noncompliance in the voluntary stage. This policy adjustment eliminates the potential for a zero abatement Nash Equilibrium, thus reducing, and potentially eliminating, the coordination problem.

Due to the novelty of a voluntary/threat policy, no such program is presently being implemented, making empirical program evaluation using naturally occurring data impossible[2]. The potential social gains from firms voluntary achieving a pollution target at least cost, together with the theoretic potential for socially suboptimal behavior imply that the experimental economics laboratory an alternative testing ground for gaining a comparative perspective of how the proposed policies will work in practice.

The experimental treatments that we present here test the voluntary policy with an exogenous tax threshold developed by Segerson and Wu and the voluntary policy with an endogenous tax threshold that we propose, against the outcomes of a regulatory only policy similar to that which has been shown to be highly efficient in past experiments. In addition, we test the voluntary/threat policy in a situation in which subjects are allowed to engage in costless, nonbinding communication.

In the next section of the paper we provide a theoretical background for the policy introduced by Segerson and Wu and the endogenous policy that we propose. In Section III we explain the experimental design and outline five hypotheses to be tested. In

[2] Compliance mechanisms require farmers to undertake conservation measures to be eligible for some Federal aid programs. For example farmers that fail to reduce soil erosion on highly erodible land may be ineligible for some Federal benefits (USDA 2004). While this is similar to a voluntary/threat policy, the threat is based more on input decisions than on the actual effluent generated. An example of an ambient based regulatory that is actually being implemented is the *Everglades Agricultural Privilege Tax*, which provides agricultural producers in the Everglades Agricultural Area of Florida with a tax break if ambient phosphorous levels are reduced by more than 25% (Ribaudo 2004).

Section IV we present and analyze the experimental results and then conclude the paper in Section V with a summary of our findings and a discussion of their policy relevance.

II. Theoretical Background

Following Segerson and Wu, suppose in a given watershed there are n identical firms. The emissions from firm i is represented by x_i and is assumed to be unobservable. The total ambient pollution in the watershed, X, is equal to the total emissions of the n firms ($X = \sum_{i=1}^{n} x_i$).

Each firm chooses its level of abatement, a_i. Abatement is related to emissions through the function $a_i = \gamma - x_i$ such that $x_i \le \gamma$, where γ is the emissions level corresponding to zero abatement. The cost of abatement for each firm is represented by the function $C(a_i)$, with $C'(a_i) > 0 \;\forall\; a_i$. Given that abatement is costly for the firm, in the absence of any policy intervention we expect $a_i = 0$, which implies that $\gamma = x_i$ and ambient pollution is given by $X = n\gamma$.

Now suppose that a social planner is interested in reducing ambient pollution to some exogenously determined target, which we denote X^s, with $X^s < n\gamma$. The target could be based on a Total Maximum Daily Load (TMDL) requirement or simply be a product of political bargaining. The social planner's problem and corresponding Lagrangian then becomes:

$$\text{Min} \sum_{i=1}^{n} C(a_i) \quad \text{s.t.} \quad \sum_{i=1}^{n} (\gamma - a_i) \le X^s, \quad a_i \ge 0, \quad x_i \ge 0 \tag{1}$$

$$\text{L} = -\sum_{i=1}^{n} C(a_i) + \lambda \left(X^s - \sum_{i=1}^{n} (\gamma - a_i) \right) \tag{2}$$

Given our assumption of homogeneity among the *n* firms and the strict monotonicity of the cost function, the constraint implies that $a_i^* = \gamma - \frac{X^s}{n}$. Additionally, the FOCs imply that $\lambda^* = C'(a_i^*)$, where λ can be interpreted as the marginal benefit of relaxing the ambient target, X^s, by one unit.

II.a Regulatory Policy

Now suppose that the social planner is attempting to reach the ambient pollution target at least cost through the use of a per unit tax on total ambient pollution applied to all firms. By imposing a marginal tax $\tau = \lambda^*$ on units of pollution in excess of X^s, the cost minimization problem for firm *i* becomes:

$$\text{Min } C(a_i) + \tau\left(X_{-i}^R + (\gamma - a_i) - X^s\right) \tag{3}$$

where X_{-i}^R are the emissions from all other firms in the market. If τ is a marginal tax on pollution units above X^s and a marginal subsidy on units below X^s, firm *i* will solve the FOC such that $C'(a_i) = \tau$ and since $\tau = \lambda^*$ then $C'(a_i) = C'(a^*)$ and $a_i = a^* = \gamma - \frac{X^s}{n}$. Since τ is strictly a marginal tax, however, firm *i's* optimal response will depend on its beliefs about the abatement activities of the other firms in the market. If abatement efforts of other firms in the market are low enough, then firm *i* will play a^*. The complete best response function for firm *i* is:

$$\begin{aligned}
a_i &= 0 && \text{If } X_{-I}^R \le X^s - \gamma \\
a_i &= X^s - X_{-I}^R + \gamma && \text{If } X^s - \gamma < X_{-I}^R < \frac{n-1}{n} X^s \\
a_i &= \gamma - \frac{X^s}{n} && \text{If } \frac{n-1}{n} X^s \le X_{-I}^R
\end{aligned} \tag{4}$$

Without loss of generality, suppose that we have two firms in the market. If firm *i* believes that firm *j* will play $a_j > \gamma - \frac{X^s}{2}$, then firm *i*'s optimal abatement[3] will be less than $\gamma - \frac{X^s}{2}$. However, if $a_i < \gamma - \frac{X^s}{2}$ then firm *j* will play $a_j = \gamma - \frac{X^s}{2}$ and therefore we do not have an equilibrium. Alternatively suppose that firm *i* believes that firm *j* will play $a_j < \gamma - \frac{X^s}{2}$. In this case, firm *i* should play $a_i = \gamma - \frac{X^s}{2}$. Note, however that if *i* plays $a_i = \gamma - \frac{X^s}{2}$ then firm *j* should also play $a_j = \gamma - \frac{X^s}{2}$ and thus strategy $a^* = \gamma - \frac{X^s}{2}$ is a unique NE. When both firms in the market play a^*, $X = 2\left(\gamma - \left(\gamma - \frac{X^s}{2}\right)\right) = X^s$. Therefore, given the marginal tax $\tau = \lambda^*$, the unique Nash Equilibrium (NE) is for each firm to play a^*, and therefore the ambient pollution target is met at least cost. Note that although any $\tau > \lambda$ will also result in the pollution target being met there is the potential for asymmetric NE, since playing a^* is no longer a strictly dominant strategy after iterative deletion.

An important feature of this mechanism is that we can introduce a tax threshold, denoted $\bar{X}$, with $\bar{X} \leq X^s$ for X^s, in equation (3) and still maintain the unique NE, $a^* = \gamma - \frac{X^s}{n}$. Setting $\bar{X}$ further below X^s has the effect of increasing tax payments, but a^* remains the optimal choice for each of the *n* firms. When the tax mechanism is used in conjunction with a voluntary approach as a background threat, lowering the threshold

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[3] $a_j > \gamma - \frac{X^s}{2}$ is a strictly dominated strategy and therefore it is actually not rational for firm *i* to believe that this strategy would be played.

serves to increase the punishment for noncompliance. We can then substitute into equation (3) to define the cost to each firm of a given combination of $\overline{X}$ and X^s as:

$$C_i^* \, (\overline{X}, \, X^s) = C(a^*) + \tau\left(X^s - \overline{X}\right) \tag{5}$$

II.b Voluntary Policy with Threat of Regulation

Now, instead of simply imposing the regulatory regime introduced above, suppose that the policy maker instead allows firms to meet the pollution target voluntarily. Again, since abatement is expensive to the firm, we would expect that a purely voluntary system would result in zero abatement. However, now suppose that the policy maker allows firms to respond to the pollution target voluntary, but also includes a threat of regulation if the target is not achieved. Specifically, if ambient pollution is above the target then the regulatory system described above is put into place. For the target to be met voluntarily, the threat induced by the regulatory regime must be sufficiently large so as to induce a Subgame Perfect Nash Equilibrium (SPNE). We have already shown that in each period of the regulatory subgame, the NE is for each firm to choose a^* so that the ambient target is exactly attained, irregardless of the particular $\overline{X}$ that is chosen. We now show that in the voluntary period, choosing a^* is also a NE.

Assume that if the ambient target is not met voluntarily, then the regulatory policy is imposed for *K* periods. This is a variation on Segerson and Wu, who assume that the regulatory policy is imposed in perpetuity. However, limiting the tax periods is important for purposes of experimental testing, and is akin to a situation where the regulator gives firms a second chance to comply voluntarily. Above we have shown that choosing a^* in each of the regulatory periods is a unique NE. In the voluntary period, each firm is therefore faced with a choice between paying the costs of abatement necessary to achieve the pollution target or not abating and facing the costs imposed by the regulatory regime. The firm will choose to abate voluntarily if:

$$(K+1)C\left(a_i^v\right) \leq K\left(C(a^*) + \tau\left(X^s - \overline{X}\right)\right) \tag{6}$$

Equation (6) implies that by simply setting $\overline{X}$ sufficiently below X^s, the policy maker can produce an incentive strong enough such that all firms should voluntarily meet the ambient target. When $\overline{X} = X^s$, under optimal abatement tax liabilities are zero with the tax mechanism, such that the firm is indifferent between voluntary and tax mechanism compliance. Under these conditions, firms can be made strictly better off by abating zero in the first period and abating to $a^* = \gamma - \frac{X^s}{n}$ in the tax periods.

Although equation (6) hints at an equilibrium whereby all firms optimally abate to meet the pollution target voluntarily, this is not the only equilibrium in the model. Similar to the regulatory setting, each firm's decision in the voluntary setting will depend on its beliefs about the actions of the other firms in the market. The best response function in the voluntary case is slightly more involved than in the regulatory case, because depending on the severity of the regulation there is a wider range of abatement choices that could be optimal. Including the superscript V to represent conditions in the voluntary setting, the best response function for firm i is:

$$\begin{aligned} a_i^V &= 0 && \text{If } X_{-i}^V \leq X^s - \gamma \\ a_i^V &= X_{-i} + \gamma - X^s && \text{If } X^s - \gamma < X_{-i}^V \text{ and } C\left(X_{-i}^V + \gamma - X^s\right) \leq K\tau\left(X^s - \overline{X}\right) \\ a_i^V &= 0 && \text{If } C\left(X_{-i}^V + \gamma - X^s\right) > K\tau\left(X^s - \overline{X}\right) \end{aligned} \tag{7}$$

If firm i expects the n-1 firms to play $a_{-i}^V = 0$, then the cost of firm i meeting the ambient target is given by $C\left(n\gamma - X^s\right)$. Firm i will only be able to meet the ambient target if $X^s \geq (n-1)\gamma$, since $a_i^V \leq \gamma$. If it is not possible for firm *i* to meet the target voluntarily, then it too will play $a_i^V = 0$. Additionally, if it is possible for firm *i* to meet the target, but the cost of abatement is greater than $K\tau(X^s - \overline{X})$, then it will play $a_i^V = 0$. Therefore in the voluntary setting there exists a NE strategy of zero abatement, unless the group size is small, the ambient target is not very restrictive and $\overline{X}$ is set low relative to X^s.

Inspection of the best response function for firm *i* also reveals the potential for a symmetric NE, identical to the regulatory scenario, whereby each firm chooses an optimal abatement strategy $a_i^V = a^* = \gamma - \frac{X^s}{n}$ that results in the ambient pollution target being met at least cost. If the n – 1 firms play a^* then firm *i* must also play a^* for the target to be achieved. If $C(a^*) \leq K\tau(X^s - \overline{X})$ then firm *i* should play a^*, as abating less than a^* will result in the target not being met and firm *i* will have to incur the costs of the regulatory policy. Abating more than a^* results in additional abatement costs with no benefit in terms of lower regulatory costs and therefore firm *i* has no incentive to deviate from playing a^*.

The symmetric NE, $a^* = \gamma - \frac{X^s}{n}$, is not trembling hand perfect. If firm *i* believes that there is some positive probability that one of the other firms will make a mistake, then its best strategy may be to play $a_i^V = 0$. In addition, there is the potential for asymmetric NE whereby the ambient target is achieved, if $\overline{X}$ is sufficiently below X^s. To see this, suppose that one of the n – 1 firms plays $a_j = a^* - \mu$, which is less than a^*. Now firm *i* will choose to meet the target voluntarily if $C(a^* + \mu) \leq K\tau(X^s - \overline{X})$ and otherwise it will play $a_i^V = 0$. Suppose that $C(a^* + \mu) < K\tau(X^s - \overline{X})$ and therefore firm *i* plays $a_i^V = a^* + \mu$ and the ambient target is met voluntarily. In this case, none of the n – 1 firms have an incentive to deviate from their strategy, since any increase in abatement will impose costs with no benefit in reduced liability and any decrease in abatement will result in the target not being met and subsequent regulation.

Although the asymmetric NE still results in the ambient pollution target being met, the costs of meeting the target are not minimized. Further, the number of asymmetric equilibria grows as $\bar{X}$ diverges further from X^s. There is therefore an essential tradeoff in the choice of $\bar{X}$ between setting $\bar{X}$ low, thereby generating a larger incentive to meet the target voluntarily but opening the door to a greater potential for asymmetric NE, and setting $\bar{X}$ higher (although still below X^s) so that the number of symmetric NE is reduced, or even eliminated, but the incentive to meet the ambient target is not as great.

Although the existence of asymmetric equilibria is a potentially troublesome result, especially if it produces gross inequities in the costs imposed by the policy, it seems likely that a more problematic outcome occurs when all firms play a zero abatement strategy in the voluntary round. In past experimental analyses, ambient regulatory policies that involved a zero abatement NE in addition to the optimal compliance symmetric NE showed significantly lower levels of social efficiency than ambient policies with a unique symmetric NE (Spraggon 2002, Vossler et. al. 2006). Unfortunately the choice of $\bar{X}$ alone likely cannot eliminate the zero abatement NE when many firms are operating in the watershed and/or the ambient pollution target, X^s, is low relative to the zero abatement baseline.

II.c Voluntary Policy with Endogenous Threat

To eliminate the existence of the zero abatement equilibrium, Segerson and Wu suggest applying the regulatory tax retroactively. In other words, if the group does not voluntarily meet the ambient standard, they would face regulation in future periods and would also be forced to pay a tax on total emissions in the voluntary period. While this does eliminate the incentive of playing the zero abatement strategy in the voluntary period, it seems to negate much of the political attractiveness introduced by the voluntary policy. In addition, collecting taxes retroactively would likely pose a significant challenge if the time period between when the emissions occur and when the taxes are collected is large and significant entry and exit occurs in the market.

Retaining the flavor of the retroactive tax, while addressing some of the practical difficulties of applying a tax retroactively, we develop a new policy instrument where the tax threshold is endogenously set. In particular, the tax threshold is determined by the level of noncompliance in the voluntary period. Formally, the tax payments due in the regulatory rounds are defined as:

$$\text{Tax Payment} = \tau\left(X^R - \left(X^s - \varphi\left(X^V - X^s\right)\right)\right) = \tau\left(X^R - \left((1+\varphi)X^s - \varphi X^V\right)\right) \quad (8)$$

where $\varphi > 0$ is a scaling parameter freely chosen by the regulator. It can be seen that the threshold decreases as the amount of pollution in excess of the voluntary target increases, thus making the consequent tax mechanism more costly to firms. Increasing φ further lowers the threshold.

We have already shown that in the regulatory setting, any tax threshold at or below X^s will induce a unique symmetric NE of playing $a_i^R = a^* = \gamma - \frac{X^s}{n}$, which implies that the ambient target is met at least cost in the regulatory setting. We can therefore simplify the tax payment expression and multiply it by K to determine the regulatory penalty of not meeting the target voluntarily.

$$\text{Regulatory Penalty} = K\tau\left(\varphi\left(X^V - X^s\right)\right) \qquad (9)$$

In the voluntary setting, each firm now faces a slightly different tradeoff. The firm will again weigh the cost of abatement against the cost of the expected regulatory penalty, however the severity of the expected tax payments are a function of the firms' abatement decision in the voluntary round. We can now define a positive level of abatement that each of the n identical firms will undertake even if they believe that the other firms will not abate. To do this, suppose that firm i believes that the abatement efforts of the other firms are low enough such that the ambient target will not be met no matter how much abatement effort it undertakes. Firm i will therefore solve a cost minimization problem given by:

$$\text{Min } C\left(a_i^V\right) + K\tau\varphi\left(X_{-I} + \gamma - a_i^V - X^s\right) \qquad (10)$$

The FOC implies that firm i will minimize its expected costs when $C'\left(a_i^V\right) = K\tau\varphi$. Recall that the marginal tax $\tau = \lambda^* = C'(a^*)$ and therefore $C'\left(a_i^V\right) = K\varphi C'(a^*)$. When the policy maker sets $\varphi = 1/K$, the strict monotonicity of the cost function implies that $\tilde{a} = a^*$ (where $\tilde{a}$ denotes the optimal individual level of abatement in the voluntary setting), meaning that the maximum amount that any firm should voluntarily abate is the socially optimal amount. If $\varphi > 1/K$ then $\tilde{a} > a^*$ and firms can find it individually optimal to abate more than the socially optimal level. If $\varphi < 1/K$ then $\tilde{a} < a^*$ and therefore meeting the ambient target is no longer an expected outcome. The best response function for firm i in the voluntary round is given by:

$a_i^V = 0$ If $X_{-I}^V \leq X^s - \gamma$

$$a_i^V = X_{-I} + \gamma - X^s \qquad \text{If } X^s - \gamma < X_{-I}^V \text{ and } C'\left(X_{-I}^V + \gamma - X^s\right) \le K\tau\varphi \qquad (9)$$

$$a_i^V = \tilde{a} \qquad \text{If } C'\left(X_{-I}^V + \gamma - X^s\right) > K\tau\varphi$$

It is easy to show that zero abatement can no longer be a NE strategy. Even if all other firms play zero abatement, as long as the abatement cost function is smooth, firm *i* can gain some positive benefits by abating to the point where $C'\left(a_i^V\right) = K\varphi C'(a^*)$. Additionally, we can show that as long as $\varphi \ge 1/K$, then a^* is a symmetric NE since none of the firms will have an incentive to deviate from the a^* strategy. If all n – 1 firms play a^* and firm *i* plays $a_i^V < a^*$ then the ambient target will not be achieved and firm *i* will face an expected regulatory penalty of $K\tau\left(\varphi\left(X^V - X^s\right)\right)$, which is greater than $C(a^*)$. If firm *i* plays $a_i^V > a^*$, then total emissions will be less than the ambient target and firm *i* will have excessive abatement costs. Therefore firm *i* should not deviate from the strategy of playing $a_i^V = a^*$. If $\varphi > 1/K$ then the possibility for asymmetric NE does exist. The proof is similar to that made in the voluntary policy with the exogenously determined threshold. When $\varphi = 1/K$, however, then the most any firm would be willing to abate is a^* and therefore it is not rational for any firm to think that the ambient target will be met if it abates less than a^*. Further, since $C(a^*) < \tau\left(X^V - X^s\right)$ for any $X^V > X^s$, it will never be individually optimal to exceed the ambient target.

The choice of φ again represents a tradeoff between a stronger incentive (when φ is large) and the creation of multiple asymmetric equilibria. The important result of this policy, however is that as long as $\varphi > 0$, the zero abatement NE is eliminated. Even if a firm believes that the ambient pollution target will not be met it is still in its best interest to abate and avoid higher future tax payments.

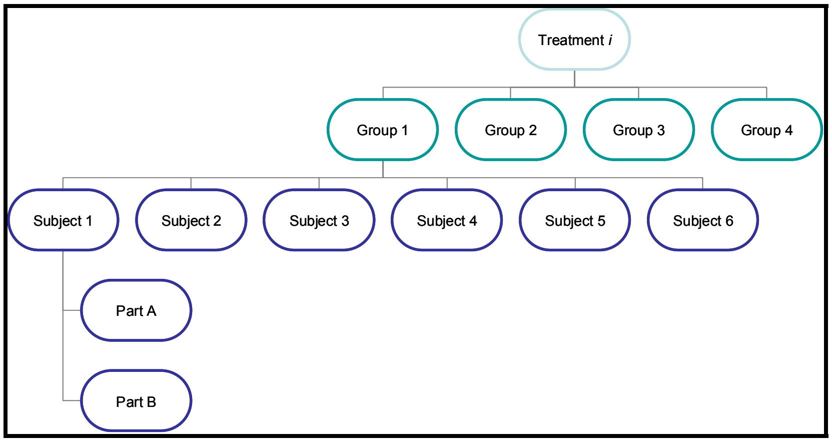
III. Experimental Design

To test hypotheses related to the theories presented above, a series of economics experiments were conducted at the Cornell Lab for Experimental Economics and Decision Research in the Spring semester of 2006. Participants had taken at least one class in economics and the majority had participated in at least one prior economics experiment. The experimental sessions lasted approximately one hour and participants earned experimental tokens during each decision round, which where exchanged for dollars at the end of the experiment at the known rate of 70,000 tokens per $1US. Average subject earnings were $20.

There are six experimental treatments and each treatment was comprised of four separate experimental groups made up of six subjects. The decision task faced by participants was cast in terms of an emissions decision, rather than an abatement choice. This is because the term abatement implies reducing emissions from previous experimental rounds, which would seem confusing to participants. Recall that emissions are related to abatement through the function $x_i = \gamma - a_i$. A level of emissions was chosen in each of at least 23 decision rounds[4], which were split up into Part A (rounds 1-5) and Part B (rounds 6-23). The hierarchical structure of the experiment is illustrated below in Figure 1.

Figure 1: Hierarchical structure of experiment

[4] The actual number of rounds was random, however each group completed at least 23 rounds.



Preceding parts A and B, participants read through a set of written instructions and viewed a Powerpoint presentation by the experiment administrator. In Part A, no policy mechanism was in place and participants simply had to choose the level of emissions that maximized their individual earnings. In part B, subjects faced one of the six policies listed below.

Table 1: Treatment Summary

	Policy Scenario	**Tax Threshold** $(\overline{X})$	**Communication Allowed**
Treatment 1	Tax Only	72	No
Treatment 2	Tax Only	50	No
Treatment 3	Voluntary/Threat	66	No
Treatment 4	Voluntary/Threat	50	No
Treatment 5	Voluntary/Threat	50	Yes
Treatment 6	Voluntary/Threat	Endogenous	No
4 groups per treatment, 6 participants per group, 138 total subjects			

In each treatment all participants faced an identical abatement cost function, which is given by $C(a_i) = \delta a_i^{\alpha}$. Because the term abatement has connotations that imply reducing emissions from previous experimental rounds, we defined the subject's decision as an emissions decision rather than an abatement decision. Recall that emissions are related to abatement through the function $x_i = \gamma - a_i$. Each subject was given an *"Emissions Decision Sheet"* that listed the "firm earnings" associated with all possible levels of emissions. To give real-world relevance to the experimental parameters, the baseline ($a_i = 0$) "firm earnings" were chosen to proximate the net farm income of a medium sized dairy farm in New York State, operating with a herd size of 200 cows[5]. In table 2, we list the specific values for the experiment parameters.

Table 2: Experimental Parameters

Description	Functional Form	Parameter Values
Abatement Cost Function	$\delta(a_i)^\alpha$	$\delta = 13$ $\alpha = 3$
Firm Earnings	$Y = Y^0 - \delta(a_i)^\alpha$	$Y^0 = 75{,}000$
Firm Level Emissions	$x_i = \gamma - a_i$	$\gamma = 20$
Ambient Pollution	$X = \sum_{i=1}^{n} x_i$	$n = 6$
Regulatory Only Policy	Tax payment = $max[\tau(X - \overline{X}), 0]$	$\tau = 2{,}500$ $\overline{X}$ = See Table 1
Voluntary/Threat Policy	<u>Voluntary Round</u> Tax payment = 0 <u>Regulatory Round</u> Tax payment = $max[\tau(X - \overline{X}), 0]$ (*instituted for* K *rounds if* $X > X^s$ *in voluntary round*)	$\tau = 2{,}500$ $\overline{X}$ = See Table 1 $K = 3$

In part B of each treatment, the policy instrument was designed to induce a 40% reduction in ambient pollution levels, from an unconstrained level of $n\gamma$ = 6*20 = 120 to an ambient target (X^s) of 72. The 40% level was chosen so as to mirror the 40% nutrient reduction goals called for in the original Cheseapeake Bay Agreement (CBP 2005). To reach the ambient target of 72 at least cost, each of the six participants need to reduce

[5] The average herd size and farm income amounts were determined based on the *New York State Dairy Farm Summary* reports produced by Cornell University for the years 1999-2003.

their emissions to 12, from the unconstrained optimum (γ) of 20. 12. This implies an optimal abatement amount ($a*$) of 8 for each subject.

For the Tax Only treatments, each subject paid a tax of 2,500 tokens for every unit of total emissions (X^R) above the tax threshold ($\overline{X}$). Given that the marginal cost of abatement is greater than 2,500 tokens for abatement levels over 8 and less than 2,500 for abatement levels of 8 and less, each firm should optimally abate exactly 8 units, which means that they will choose to emit 12 units and the ambient target of 72 will be exactly met as long as the tax threshold is 72 or less.

In Treatment 1, the tax threshold is set equal to the ambient target of 72. This follows the policy shown to be highly efficient in the experimental studies of Spraggon (2002), Poe et. al. (2004), Cochard et. al. (2004) and Suter et. al. (2005) and serves as the baseline for evaluating the results of the voluntary/threat policy. In Treatment 2, the tax threshold is set at 50. Strategy $a*$ is a unique NE for any tax threshold at or lower that 72 with τ =2,500. However, when the tax threshold is strictly lower than 72 the group can maximize its payoff by abating more than $a*$. While collusive outcomes of this nature were not seen in recent experimental results when total pollution was a stochastic function of total emissions (Suter et al. 2005), it is an open empirical question whether subjects behave in a more collusive manor in the non-stochastic environment presented in this study. Treatment 2 also allows us to compare the results of the tax only policy to the regulatory portion of the voluntary/threat policy in treatment 4, which also has a tax threshold of 50.

In Treatment 3 through 6 we evaluate the voluntary/threat policy where the voluntary ambient target is 72. In each of these treatments, the threatened regulatory regime consists of three rounds (K=3). Three rounds were selected to allow for multiple observations of the voluntary scenario while still capturing the essence of a threat where subjects pay a penalty over time for not meeting the target as suggested by Segerson and Wu.

In Treatments 3 and 4, the threatened regulatory policy has tax thresholds of 66 and 50 respectively. The threshold of 66 is low enough so as to provide the necessary incentives for subjects to abate voluntarily to meet the target, given that they believe that all other subjects will also abate. The threshold of 50 provides a stronger incentive for voluntary abatement, since the regulatory costs of not meeting the target voluntarily are higher, but also introduces the potential for a greater number of asymmetric NE. By varying the tax threshold, we therefore gain some insight into the tradeoff between a tax threshold that is relatively close to the ambient target, which reduces the number of asymmetric NE, and a low tax threshold, which increases the incentive to abate voluntarily but also increases the potential for meeting the voluntary target at higher than minimum cost.

Meeting the ambient target voluntarily at least cost requires a great deal of coordination, since all subjects must choose to emit exactly 12 units. In Treatment 5, we increase the potential for coordination by allowing groups to engage in costless, nonbinding communication (referred to in the experimental economics literature as "cheap talk"). Each of the Treatment 5 groups is allowed up to five minutes of cheap talk before rounds 6,11,16 and 21. Participants are allowed to discuss any aspect of the experiment, but are not allowed to make threats or arrange for side payments. Cheap talk was shown to greatly improve efficiency outcomes in earlier studies of the Tax Only instrument (Suter et al. 2005).

In Treatment 6, we test the voluntary/threat policy with the endogenous threshold. This policy has the positive feature of reducing incentives for under abatement, and with it the zero abatement NE. Recall from Section II that the choice of the scale parameter (φ) is in effect a choice over the magnitude of the incentive for voluntary compliance. As φ gets large, the incentive for voluntary compliance increases. A unique NE is created by setting $\varphi = 1/k$. For treatment 6 we chose φ =1, as it is our belief that a stronger incentive has a higher potential of coordinating the group on the cost minimizing voluntary abatement decision despite the potential for asymmetric equilibria. Additionally, setting φ =1 makes the policy significantly more straightforward for the subjects, since it means that every unit above 72 in the voluntary round will result in the tax threshold being set an equal number of units below 72 in the threatened regulatory round.

IIIa. Testable Hypotheses

Although the pure regulatory, the voluntary/threat with exogenous threshold, and the voluntary/threat with endogenous threshold policies all have the theoretical potential to produce outcomes whereby the ambient pollution target is met at minimum cost, the relative performance of the three mechanisms is an open empirical question. While the pure regulatory policy with a constant marginal ambient tax has proven to generate highly efficient outcomes in several past experimental studies (Poe et. al. 2004, Spraggon 2002, Cochard et. al. 2004; Suter et. al. 2005), a voluntary policy with a threat of regulation has not been subject to experimental examination. By evaluating the experimental results from the voluntary/threat policy we endeavor to test the following three hypotheses.

(1) In the voluntary/threat policy treatments, firms abate voluntarily such that the ambient pollution target is met.

(2) Lowering the threatened tax threshold ($\overline{X}$) or making the threshold endogenous makes firms are more likely to abate voluntarily, but free riding occurs.

(3) The instances of subjects choosing zero abatement are lower in the voluntary policy with the endogenous threshold than with the exogenous threshold.

Comparing the results from the regulatory only treatments to the results in the voluntary/threat treatments, we then test two additional hypotheses:

(4) The average emissions decision in each of the policy settings is identical to the Nash Equilibrium prediction.

(5) The voluntary/threat policy generates social efficiency outcomes identical to the regulatory only policy.

IV. Results

In this section we present three sets of results. We begin with a simple presentation of the results from the four voluntary/threat treatments. This presentation includes the number of rounds that each group was able to voluntarily meet the ambient pollution target as well as some evidence of how individual behavior differed across treatments. Based on these results, we draw conclusions regarding the first three hypotheses above. The second set of results use an econometric model to estimate the mean emissions decision at the participant level in each policy scenarios. This enables us to draw conclusions regarding Hypothesis 4. In the final set of results, we present social efficiency outcomes from the six treatments. These efficiency results allow for a general comparison across all six treatments and specifically allow us to compare the outcomes of the regulatory only treatments to the voluntary/threat treatments.

For all of the results presented below, our analysis covers the decisions made up to round 23, which includes 18 Part B rounds. In addition to the summary results presented below, we also include a round by round graphical depiction of the group emissions for all treatments as an Appendix.

Table 3: Number of Part B rounds in which the ambient target is met voluntarily

	No Communication			Communication
	$\overline{X} = 66$	$\overline{X} = 50$	$\overline{X}$ = End.	$\overline{X} = 50$
Group 1	6	0	0	18
Group 2	0	5	0	14
Group 3	0	18	0	18
Group 4	0	0	14	18
Average	*1.5*	*5.75*	*3.5*	*17*
(standard deviation)	*(3.0)*	*(8.5)*	*(7.0)*	*(2.0)*

Inspection of Table 3 reveals that when groups were not allowed communicate they had a very difficult time meeting the ambient pollution target in the voluntary setting. When groups are allowed to communicate in Treatment 6, however, they were able to reach the ambient target voluntarily with near certainty[6]. These results allow us to respond to Hypothesis (1).

Result 1: The hypothesis that subjects will abate voluntarily so that the ambient target is met can be rejected in the case where the subjects are not allowed to communicate, since the average number of rounds that a group met the target was not significantly different from zero. When communication does occur, then the hypothesis that groups will comply voluntarily cannot be rejected.

[6] Although group 2 did fail to meet the target voluntarily in one of the rounds (and subsequently had to go through three rounds of the regulatory policy), this was a result of a mistake made by one of the subjects. In the cheap-talk session that occurred after this mistake was made, the subject was highly apologetic to the other group members and stated that the wrong number was accidentally typed into the computer.

While lowering the tax threshold from 66 to 50 increases the probability of voluntary compliance, groups still missed the target more often than they achieved it. Even when the threshold is made endogenous and meeting the target voluntarily is the only outcome that can be explained by Nash behavior, only one of the four groups was ever able to meet the target in a voluntary round. Interestingly, the endogenous threat policy was the only scenario where a group missed the target voluntarily, but then subjects reduced emissions so as to meet the target voluntarily after experiencing the regulatory policy.

Measuring the degree of free riding when the target is met is challenging, primarily because groups generally did not achieve the target voluntarily. From the limited evidence available, it seems that free riding was not an issue. We would expect the greatest potential for free riding to occur with the voluntary policy with threatened tax threshold of 50, however we observed only one round where one subject overabated and one subject underabated (out of 23 rounds where the target was met voluntarily). In the group that met the target under the voluntary policy with endogenous threat, we observed one subject that was consistently one or two units below the optimal emissions and one consistently one or two units above. This limited evidence does not indicate the prevalence of the drastic types of free riding that are theoretically possible.

Result 2: Lowering the tax threshold and making the threshold endogenous does increase the likelihood of the ambient target being met voluntarily and we do not see strong evidence of free riding occurring.

The results above suggest that groups had difficulty meeting the target voluntarily, but to address Hypothesis (3) we need to measure the number of times in each treatment that subjects chose a zero abatement strategy (in our case zero abatement is when a subject chooses to emit 20 or more units). In the voluntary treatment with exogenous threshold of 66, subjects played the zero abatement strategy an average of 15 times per group (s.e.=4.5). The per group frequency dropped to 5.3 (s.e.=2.3) in the case of the threatened exogenous threshold of 50. Finally, in the voluntary with endogenous threshold treatments the average number of times the zero abatement strategy was played dipped to 4.5 times per group (s.e.=2.3). Note then that only when the threshold is made endogenous is the threat of regulation enough to cause the average number of subjects in a group who refuse to abate voluntarily to be not significantly different from zero.

Result 3: The endogenous threshold does reduce the number of subjects in a group that play a zero abatement strategy. Lowering the threshold also reduces the number of observed instances of zero abatement.

In addition to looking at the number of instances where subjects chose not to abate in the voluntary rounds of the experiment, it is also interesting to look at the decision subjects made in the first round in which the voluntary/threat policy was put in place (round 6). In this round each subject had to make a decision without any prior information on how other subjects would respond to the policy and therefore we get our purest test of the effectiveness of the voluntary/threat instrument.

Interestingly, the vast majority of subjects voluntarily abated at least the optimal amount. For each of the three treatments there are 24 observed decisions in round 6. The number of subjects that chose to emit 12 or fewer units was 17 (tax threshold 66), 21 (tax threshold 50) and 20 (endogenous tax threshold). The fact that over 80% of subjects voluntarily abated at or above the amount necessary to reach the target is a testament to the fact that the threat of the regulatory policy is strong.

Two intuitive hypotheses could explain why the remaining subjects refused to adequately abate. First, they believed that other subjects would not abate and therefore it was not in their best interest to abate. Second, they were either confused or they made a miscalculation regarding the payoffs of the various strategies. While we cannot make a definitive statement, it does appear that the latter explanation holds in the majority of the cases. Evidence in support of this conclusion comes from the endogenous threat treatment, where subjects should abate even if they believe that others will not follow suit. Further, we have some limited evidence from an experiment we ran where the ambient target was based on individual rather than group emissions. In this case, it is always optimal to emit 12 units, since whether or not you meet the ambient target is only a function of your own decision. In this sub-treatment we saw 2 of the 8 subjects not abate in the first policy round, approximating the twenty percent of subjects that didn't abate in the group setting.

Having twenty percent of subjects make a miscalculation in the initial period of a policy does not seem as if it should be an overwhelming obstacle. In many complicated experimental settings it takes many decision periods, and substantial learning, before theoretically optimal outcomes are achieved (if they are achieved at all). In that regard, it is important to investigate the evolution of decisions over time. In addition, since we have seen from Table 3 that the majority of groups do not meet the target voluntarily, it is also important to see what happens in the regulatory rounds of the experiment. We can then compare the results of the treatments with the voluntary/threat mechanism in both the voluntary and the tax settings, to the strictly regulatory settings of treatments 1 and 2.

To get a sense of how individual decisions vary across the treatment conditions, our objective is to generate an expectation for the emissions decision of a random subject in a random group in one of the treatment scenarios. Recall from the last section that the individual observations come from a hierarchical data generating structure, where groups are nested within treatments, subjects are nested within groups and each subject makes a decision in each of over 20 rounds. Additionally, in the voluntary/threat treatments subjects are either making a decision in a voluntary setting or in a regulatory setting. This complex data structure implies that we cannot treat each of the individual decision as an independent observation. It is reasonable to presume that there is serial correlation among the individual decisions across rounds and that the individual decisions within a round are correlated across the six subjects in the group.

To partially control for serial correlation, we have simplified matters by aggregating the rounds into two groups corresponding to the first 9 rounds of Part B and the final 9 rounds of Part B. The aggregate groupings give us a general sense of how results from early periods of the policy can be compared to later periods of the policy. In addition, the aggregation eliminates some of the complications having to do with the fact that groups that meet the ambient standard voluntarily will by definition participate in more voluntary rounds. By aggregating, we ensure that we weight the voluntary decisions made by each individual equally. It also means that each of the individual data points will be based on an average of at least two voluntary decisions.

To compare the individual emissions decisions across treatments, we estimate a mixed model with both fixed and random effects. We define a fixed effect for the first five rounds of each treatment (Part A) plus fixed effects for the relevant policy scenarios in each treatment in the 2 aggregate round groupings. For each of the regulatory only treatments we therefore have one fixed effect for Part A and two fixed effects for Part B. For each of the voluntary/threat treatments we again have one fixed effect for Part A, but now we have four fixed effects for part B corresponding to the voluntary scenario in the early rounds, the regulatory scenario in the early rounds, the voluntary scenario in the late rounds and the regulatory policy in the late rounds. We do not include the results from the session where communication was allowed as there were insufficient observations of the regulatory policy. All together that leaves us with a vector of 13 fixed effects that we define as Y. Referring to the policy scenarios as fixed effects may be confusing to economists, since generally in the panel data literature a fixed effect is added primarily to account for some unexplained heterogeneity and is "differenced away" in the estimation process. In this case, the fixed effects give us an estimate of the how a representative individual would act when presented with a given policy scenario and represents the variable of interest.

In addition to the fixed effects, we also have random effects that must be controlled for. Given the hierarchical data structure, the random effects enter at both the group and the individual level. That is, we envision each group as being drawn at random from a larger population of potential groups and each of the subjects in the groups is also being drawn at random from a larger population of subjects. While we are not interested in the decisions of a given subject or the average decision of a given group per se, we do need to control for the random elements introduced by the fact that we only have a limited random sample of groups and individuals. In our estimation equation below, we include the element α_g to represent the random intercept term for group g and the term μ_{ig} to represent the random intercept for subject *i* in group *g*. Both of the random intercept terms are assumed to be mean zero with constant variance. The term ε_{igr} captures the remaining stochastic error and is also assumed to be mean zero with constant variance. The final equation to be estimated is given by:

$$x_{igr} = \sum_{r=1}^{16} \beta_r Y + \alpha_g + \mu_{ig} + \varepsilon_{igr} \tag{10}$$

The coefficients in equation (10) were estimated using Stata's *gllamm* command and are included below in Table 4.

Table 4: Estimation Results

Dependent Variable: individual emissions Number of Observations: 366				$R^2 = 0.956$ F = 475.9*
Tax Threshold	**Part A Rounds 1-5**	**Policy Scenario**	**Part B Rounds 6-14**	**Part B Rounds 15-23**
72	20.02 *(0.453)*	**Regulatory Only**	13.46* *(0.557)*	13.63* *(0.557)*
50	19.94 *(0.374)*	**Regulatory Only**	9.91* *(0.559)*	10.62* *(0.559)*
66	19.24 *(0.555)*	**Voluntary**	14.81* *(0.556)*	17.33* *(0.556)*
		Regulatory	11.12 *(0.556)*	11.53 *(0.556)*
50	19.76 *(0.737)*	**Voluntary**	12.89 *(0.569)*	14.21* *(0.569)*
		Regulatory	9.00* *(0.635)*	9.53* *(0.635)*
Endogenous	19.69 *(0.376)*	**Voluntary**	12.88 *(0.583)*	13.83* *(0.583)*
		Regulatory	12.17 *(0.583)*	11.59 *(0.640)*
Estimated Variances		**Group Level**	4.096	
		Subject Level	3.396	
		Remaining	0.017	

* Indicates that the coefficient estimate in Part B is significantly different from 12 at the 5% level. None of the results from Part A are significantly different from 20.

The results presented in Table 4 show that in Part A of the experiment, when no policy was in place, emissions were not different from the prediction of 20. In other words, with no regulatory policy or threat of a regulatory policy in place, subjects did not abate from the unconstrained optimum. In each of the Part B policy scenarios individual emissions were significantly below 20, which suggests that all of the policies that we investigated resulted in positive levels of abatement. Individual emissions were, however, significantly different from the Nash Equilibrium prediction of 12 in each of the policy scenarios.

Result 4: The expected emissions decision deviates from the Nash prediction in either the early or late period of all of the policy scenarios.

In the regulatory only setting with the tax threshold set equal to the ambient target of 72, which serves as our baseline, the predicted emissions decision is significantly more than the optimum of 12. Despite the statistical significance of this outcome, the fact that subjects on average exceed the optimum by 10% is not large in economic terms and closely approximates earlier experiments by Spraggon (2002) and Poe et. al. (2004)[7].

When the tax threshold is reduced to 50, the expected emissions decision in the regulatory only policy is significantly less than the socially optimal decision. It appears that there is some tendency towards tax avoidance through overabatment. Each individual emitting 8 units maximizes the group's after tax profits, however since no communication can occur we expect that individuals attempting to maximize individual profits would drive the average results towards the privately optimal result of 12 units. Though limited collusive behavior does seem to be present, it erodes somewhat between the earlier and later rounds (though this erosion is not statistically significant).

In the voluntary/threat policy with an exogenous threshold of 66, the predicted individual emissions level in the voluntary setting is significantly greater than the socially

[7] Spraggon calculates average individual emissions under the tax only mechanism to be 31.84 when the social optimum is 25. Poe et. al. calculate an individual average of 5.93 when the social optimum is 5.

optimal amount. Additionally, individual emissions increase significantly between early and late rounds, indicating that the response to the regulatory threat becomes weaker over time as subjects become convinced that other group members will also not abate voluntarily. In the regulatory portion of this treatment, average emissions levels are not significantly different from the social optimum in either early or late rounds.

In the voluntary/threat policy with an exogenous threshold of 50, individual emissions are not significantly different from 12 in the early voluntary setting, however we do again see a significant increase in the later rounds. Emissions in the regulatory portion of this policy are significantly less than 12, which suggest some tendency towards tax avoidance and may serve to weaken the regulatory threat.

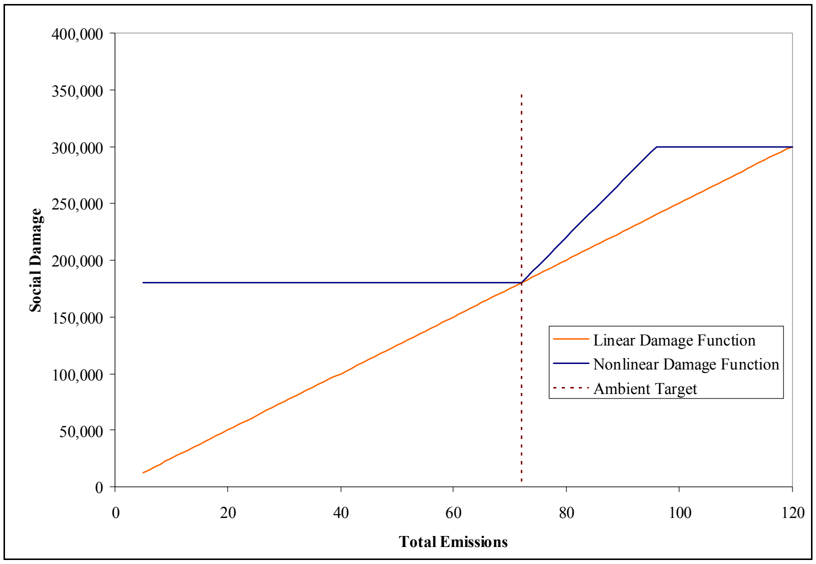
When the threatened tax threshold is made endogenous, the expected individual emissions are closer to the social optimum of 12 than any of the other treatments in both the voluntary and regulatory settings. Further, the change in expected emissions is not significant between early and late rounds in either setting, although the in early rounds expected emissions are not significantly different from 12 and in later rounds they are.

Comparing the voluntary/threat policy to the regulatory only policy we see first that in the voluntary scenario the expected emissions when the threatened tax threshold is set at 50 or is endogenous are not different from the baseline regulatory policy. Under the regulatory portion of the voluntary/threat policy, expected emissions are statistically less than the baseline regulatory policy. As mentioned earlier, the threshold of 66 and the endogenous threshold yield expected emissions that are not significantly different from the social optimum. The voluntary policy with endogenous threat therefore appears to perform as well or better than the baseline regulatory policy in both the voluntary and regulatory portions of the policy.

Estimating individual emissions decisions is important in understanding how the various policy scenarios will influence levels of pollution. It does not, however, tell us how the voluntary/threat policy compares to the regulatory only policy in regards to social efficiency. For example, if a particular policy approximates the cost minimizing emissions level for an average subject, this does not mean that costs have been minimized if there is a significant degree of variation around the mean decision.

To compare the social outcomes of the emissions decisions in the voluntary/threat policies to the regulatory only policy, we compute two efficiency measures for each treatment corresponding to two separate assumptions about the underlying social damage function. The first assumed damage function is linear in total emissions with a slope of 2,500. A linear damage function is assumed in most previous studies (e.g. Spraggon 2002; Poe et. al. 2004). The second damage function assumes that damages are positive but flat up to the ambient target of 72 and then increase at a rate of 5,000 per unit of emission above 72. We set the damages in the "flat" portion of the function equal to the damage at 72 in the linear damage function case (Damage=72*2,500) and we also cap damages at the maximum of the linear damage case (Damage=120*2,500). This type of damage function might occur if the water resource is used for drinking water. With any positive amount of pollution, the society must run its primary filtration system. Above the target level of pollution, they not only need to run the primary filtration system, but also a secondary system that exhibits increasing costs as ambient conditions worsen. The damage functions are illustrated in Figure 2.

Figure 2: Comparison of Assumed Social Damage Functions



The efficiency measure used here is identical to that introduced by Spraggon (2002). Essentially the social surplus in a given round is determined by summing the pre-tax earnings of each of the six firms in the group (the social benefit) less the social damage, determined by the aggregate emissions in that round. The observed surplus in round *t* by group *g* (S_{gt}) is then measured against the surplus in the zero abatement scenario (S_{zero}) and the maximum surplus possible (S_{max}) to give a measure of efficiency according to the formula:

$$Efficiency_{gt} = \frac{S_{gt} - S_{zero}}{S_{max} - S_{zero}} \qquad (11)$$

The baseline social surplus measures (S_{zero}, S_{max}) remain the same across the two assumed damage functions, making comparison of efficiency measures across the functions possible. The efficiency measures for each group are averaged across all of the rounds in Part B to come up with an overall group efficiency measure for each of the four groups in each treatment. The mean and standard errors for the group level efficiency measures are given for each treatment in Table 5.

Table 5: Mean efficiency levels by treatment

Treatment	**Linear Damage Function**	**Non-linear Damage Function**
Reg. Only		
$\overline{X}$ *=72*	81.5% *(3.52)*	54.1% *(1.82)*
$\overline{X}$ *=50*	64.3% *(5.16)*	28.6% *(5.28)*
Vol/Threat		
$\overline{X}$ *=66*	79.9% *(2.10)*	58.7% *(2.50)*
$\overline{X}$ *=50*	75.4% *(9.17)*	45.1% *(20.75)*
$\overline{X}$ *=Endogenous*	82.4% *(7.78)*	67.4% *(11.69)*
$\overline{X}$ *=50 (cheap talk)*	98.3% *(1.73)*	95.4% *(4.59)*

The efficiency results presented above allow us to respond to hypothesis (5),.

Result 5: The social efficiency outcomes for the voluntary/threat treatments were statistically identical or better than the social efficiency outcomes for the regulatory only treatments.

The three voluntary/threat treatments where subjects were not allowed to communicate all have mean efficiencies that are not significantly different from the regulatory only baseline, though the voluntary policy with endogenous threat had the highest efficiency of the three. When communication was allowed, the efficiency results are significantly higher than the baseline (and in fact are not significantly different from 100%). In the regulatory only setting with the threshold equal to 50, the mean efficiencies are significantly lower than all of the other treatments.

The mean efficiencies in the linear damage case are higher than the comparable efficiency estimates in the non-linear case since the non-linear damage function penalizes deviations in aggregate emissions from the ambient target more than in the linear case. In the non-linear case, the voluntary policy with endogenous threat is more efficient relative to the other non-cheap talk treatments than in the linear case, though this difference is still not significant due to the higher standard errors. The standard errors increase in the non-linear case because there is greater variation between the efficiency results of the one group that meets the target voluntarily (where the efficiency in nearly 100%) and the other three groups that did not meet the target voluntarily in both the voluntary/threat with threatened threshold of 50 and the voluntary with endogenous threat treatments.

V. Conclusion

In this paper we evaluate a policy introduced Segerson and Wu (2006) that addresses nonpoint source pollution through a voluntary policy used in combination with a background threat of regulation. We also augment Segerson and Wu's theory by showing how the severity of the threatened regulatory policy can be made endogenous to the results in the voluntary scenario thereby removing the existence of the zero abatement NE. Using results from a set of economics experiments, we test several parameterizations of the voluntary policy with the background threat of regulation in the experimental economics laboratory and compare it to the results of a similarly designed regulatory only policy. The results of the experimentation show that although lowering the threatened exogenous tax threshold or making the threshold endogenous do increase the probability that a group will meet the ambient target voluntarily, the target is still met by only approximately 25% of the groups where communication is not allowed. When participants are allowed to communicate, the story is much different as the probability that a group meets the ambient target voluntarily improves to nearly 100% with essentially no free riding. This positive result again illustrates the findings of Poe et. al. (2004) and Vossler et. al. (2006) that communication can greatly improved social outcomes.

Despite the fact that the majority groups did not meet the ambient target voluntarily in the absence of communication, the political attractiveness of allowing firms the opportunity to meet a target voluntarily remains. In addition, in the 25% of the groups where the ambient target was met, policy makers would not need to expend the resources necessary to implement the regulatory system.

When the ambient target is not met voluntarily, the regulatory system that is imposed should still theoretically result in the ambient target being met at least cost. Our experimental results suggest, however, that this may not necessarily be the case. Lower levels of the tax threshold may in fact introduce a greater potential for over abatement in the regulatory setting and therefore be undesirable. This leaves us with somewhat of a quandary in that the high exogenous threshold appears not to provide a strong enough incentive to convince all individuals to abate voluntarily and the lower threshold exhibited over abatement in the groups that did not meet the ambient target voluntarily. Fortunately, when the threshold in the regulatory policy is endogenous to the outcome of the voluntary policy, groups are more likely to meet the target voluntarily and the groups that do not abate voluntarily exhibit optimal abatement levels in the regulatory policy.

Finally, our results show that in the three voluntary/threat policy treatments without communication, measured social efficiency levels were not significantly different from the baseline regulatory only policy advocated by previous studies. The voluntary/threat policy therefore provides significant political advantages in that landowners have an opportunity to reduce emissions voluntarily and avoid direct regulation while at the same to generating economic outcomes that are as good as or better than a strictly regulatory approach.

The optimistic viewpoint that we take regarding a voluntary/threat policy certainly could be bolstered with future research on variations of the policies tested here. Specifically, it would be interesting to see if increasing the severity of the endogenously determined threat by varying the scale could improve the probability that groups meet the target voluntarily. Further, we did not examine how changing the number of rounds (K) or adding a stochastic component to the experiment influences the probability that an individual will abate optimally in both the voluntary and regulatory settings. Finally, seeing as the results were highly favorable when subjects were allowed to communicate, it would be interesting to see if this result remains when cheap-talk is replaced by "cheap listening" or through voluntary individual reporting.

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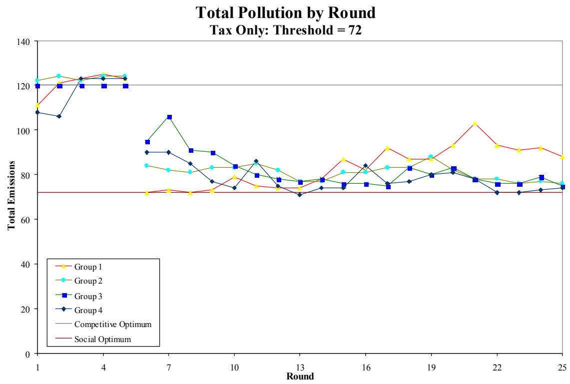
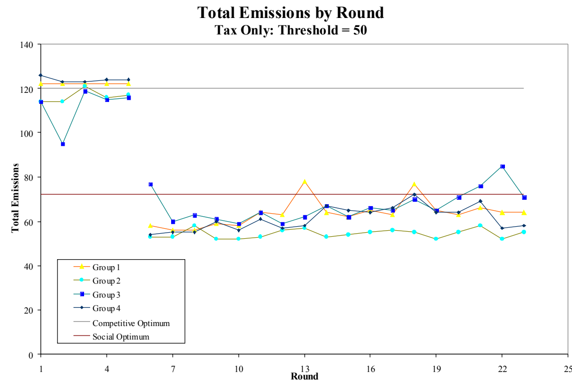
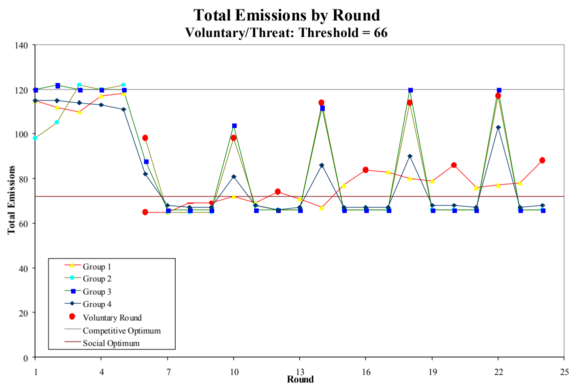
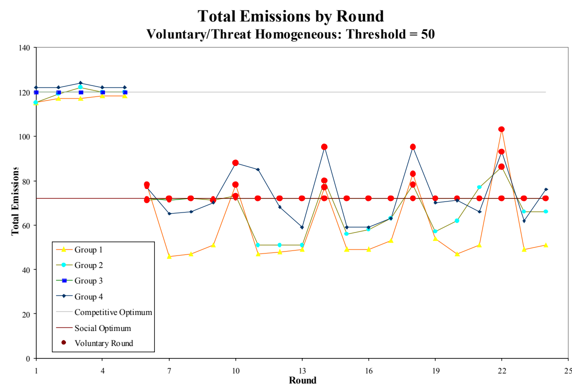
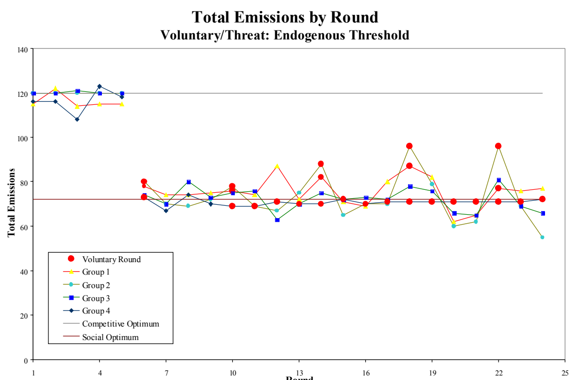
Appendix

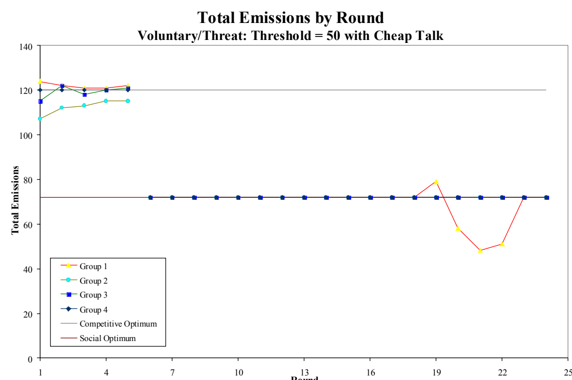

Total Pollution by Round
Tax Only: Threshold = 72
Total Emissions
Round
Group 1
Group 2
Group 3
Group 4
Competitive Optimum
Social Optimum


Total Emissions by Round
Tax Only: Threshold = 50
Total Emissions
Round
Group 1
Group 2
Group 3
Group 4
Competitive Optimum
Social Optimum


Total Emissions by Round
Voluntary/Threat: Threshold = 66
Total Emissions
Round
Group 1
Group 2
Group 3
Group 4
Voluntary Round
Competitive Optimum
Social Optimum


Total Emissions by Round
Voluntary/Threat Homogeneous: Threshold = 50
Total Emissions
Round
Group 1
Group 2
Group 3
Group 4
Competitive Optimum
Social Optimum
Voluntary Round


Total Emissions by Round
Voluntary/Threat: Endogenous Threshold
Total Emissions
Round
Voluntary Round
Group 1
Group 2
Group 3
Group 4
Competitive Optimum
Social Optimum


Total Emissions by Round
Voluntary/Threat: Threshold = 50 with Cheap Talk
Total Emissions
Round
Group 1
Group 2
Group 3
Group 4
Competitive Optimum
Social Optimum